PTTI 2030 – TIME TRANSFER AND APPLICATIONS IN 2030

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Abstract

Current time-transfer techniques using Two-Way Satellite Time Transfer (TWSTT) and Global Positioning System (GPS) Carrier-Phase differencing offer excellent Precise Time and Time Interval (PTTI) accuracy and stability for only a few high technology laboratories and weapon systems. Today's costs of these systems impede their use in systems where performance gains are possible. However, future research and development will likely extend today's leading edge PTTI capabilities economically to greater numbers of laboratories, systems, and users in the years to come. This poster examines the potential future applications of much improved mainstream time transfer and hyper-accurate time transfer for precise applications, as well as identifying foreseen potential hurdles along the way.

THE EXERCISE

At the 41st annual Precise Time and Time Interval (PTTI) Meeting, participants were asked to ponder PTTI issues in the year 2030. Several subjects were offered as potential areas where PTTI papers might be developed two decades hence. Each participant was urged to join a group based on their interest in the future subject title. There were seven groups. Each group was tasked to come up with the top five future presentations and present them before the other groups. Towards the end of the session, each group presented the guiding ideals behind their selections and the titles of the papers to be presented at the 62nd Annual PTTI Meeting. Finally, each group was tasked to provide two members, a senior standing member in the PTTI field and the youngest participant, to create a poster for the next PTTI conference in 2010 detailing the findings of the group and identifying potential hurdles to achieving the foretold accomplishments **[1]**. This paper predicts the subject titles of papers presented at the 62nd Annual PTTI Meeting to be held in November, 2030, and the rationale behind these predictions.

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THE CURRENT STATE OF TIME TRANSFER

The transfer of time in today's society is paramount. Every day billions of people worldwide depend on some level of time synchronization, and timing laboratories require time transfer to evaluate the quality of their locally generated timescale. Everything from home computers and cell phones to very expensive atomic timescales are connected through various means of time transfer. Time transfer occurs over distances from a couple of meters to half way around the world.

The accuracy and stability of time transfer via either Global Positioning System (GPS) Carrier-Phase differencing or Two-Way Satellite Time Transfer (TWSTT) is comparable. However, the calibration is perhaps better understood for TWSTT systems, which make it the primary method for accurate long distance time transfer. The instability at 1 day is less than 1 nanosecond. The cost of a TWSTT system is very high, however. There is also the matter of keeping a large antenna on the roof and having a clear view of a particular section of sky. This prohibits its use in widespread applications.

Network Time Protocol (NTP) is the most common inexpensive method of distant time transfer. It is used in most computers connected to the Internet. Its ability to synchronize two clocks is around 16 ms **[2]**, but the level of synchronization is highly dependent on the route the NTP messages take through the Internet. Shorter distance between nodes and greater consistency in the route of the NTP packets yields better timing results. NTP cannot match the accuracy of either GPS or TWSTT, but does provide time transfer accuracy that today is good enough for more than 99% of users.

TIME TRANSFER IN 2030

To achieve the environment necessary for the following future papers to be written, several technologies are projected to become mature. The first GPS III launch is scheduled for 2014 **[3]**. By 2030, there should be a full constellation of GPS III satellites. GPS III represents a gradual evolution of time transfer. Newer GPS satellites come equipped with better clocks, which improve GPS Time itself, since GPS Time is an ensemble of all GPS satellites and ground clocks. This enables real-time time-transfer accuracies that are beyond what is available today through GPS. Of course, there is always the potential for program delays that would push back the arrival of a full complement of GPS III satellites. This is the first of many hurdles that will be encountered that endanger the realization of PTTI 2030 as seen in this paper. The prediction is that by 2030, the GPS III satellites, combined with improved timescale algorithms, will enable local clocks to consistently maintain timekeeping accuracies within 1 nanosecond of UTC (USNO)[1].

Another technology expected to become prevalent by 2030 is the Precision Time Protocol (PTP), also known as IEEE-1588. PTP offers accurate levels of time transfer over local area networks that is much more accurate than NTP. It provides accurate timing services in areas that cannot feasibly install a GPS timing receiver at each node, whether the reason is cost or location. The prediction is that by 2030, the performance of PTP-based networks should be better than 100 ns, which may already be feasible **[4]**.

[1]This is a common way of referring to the real-time laboratory realization of the paper timescale known as Coordinated Universal Time (UTC). In this case, USNO is the laboratory.

A special mention was made of wireless 1588. For PTP to work, the local area network has to be predictable. Specifically, the PTP packets need to take the same route and encounter the same delays each time when traversing that route. Additional delays in the wireless router must be taken into account to reduce jitter in measurements. Specific routers may need to be built to maximize the effectiveness of PTP over a wireless local area network, or at least a network with a wireless component.

Another prediction is that all-optical networks will exist. Such a network would be extremely fast and predictable, not suffering the same sort of interference delays that a similar metal-wire-based network would be prone to. The big obstacle here is interest. The big corporations and institutions that would be responsible for the construction of a network this size will need profitable reasons to include timing functionality in it. The advantages of having a continental – or even intercontinental – fiber network available to making clock comparisons would be significant. Such an underlying infrastructure would greatly aid the next prediction.

The final prediction made is that the International Bureau of Weights and Measurements (BIPM) will have a real-time distribution of UTC by 2030. This would require the participation of timing laboratories around the world and involves streaming real-time measurement data to the BIPM. The data streams of the timing laboratories would then be combined and filtered and a weighted average constructed of the final information. That final value would be delivered to users seconds after the initial data was delivered to BIPM. Much progress has already been made with a similar concept at the International GNSS[2] Service (IGS) with the Real-Time Pilot Project. However, problems may emerge due to a number of issues. Laboratory participation may not be as high as necessary. There may be significant bandwidth concerns for the BIPM and for laboratories that have many clocks with data to stream.

PAPERS IN TIME TRANSFER AND APPLICATIONS AT PTTI 2030

With the appropriate assumed advances in the underlying systems outlined, potential papers to be delivered at the 62nd Annual PTTI Meeting will now be examined. A common hurdle with the below papers is extending the knowledge of PTTI to other fields. If a benefit, especially a competitive advantage, can be found by utilizing new PTTI technologies in future or existing products, companies will leap on board. But if they are not aware of potential applications, they will not implement them. Another common theme, in the same spirit as the previous, is to get the engineers and designers from those respective fields to attend the PTTI Meetings and related PTTI gatherings. Then they will be exposed to PTTI technologies and be able to develop their own ideas regarding the benefits of PTTI and how/why to implement PTTI applications to achieve better and/or cheaper products.

APPLICATIONS OF INTERNET/GPS-III NANOSECOND-LEVEL TIME TRANSFER

With the widespread arrival of relatively cheap nanosecond-level time transfer through either the Internet or GPS III, papers will likely arise outlining some applications which may not have been possible before, or would not have been previously feasible within an established budget. In addition to GPS III, there will likely be other fully featured GNSSs available, leading to a very robust and available position solution. Combined with a Quality of Service (QoS) message, available now primarily from Satellite-Based Augmentation Systems (SBAS) and in 2030 likely from any number of systems, total autonomous vehicular navigation should be possible, both on the ground, by sea and in the air.

[2] Global Navigation Satellite System

In 2030, transactions will likely be capable of being timestamped at the nanosecond level. This creates the possibility of new automated trading servers located in close proximity to the stock market servers being created to maximize the potential for priority positioning of trade requests. In any mass market electronic distribution, such a precise time accuracy can ensure that first come is really first served. For instance, if a new product is to begin pre-sale at a certain time online, the rush of pre-orders will be able to be dealt with in the proper order based on the time of reception of the pre-order request, rather than by a less precise or arbitrary process.

Comparisons of laboratory clocks over the Internet will be another application. The stated 1-nanosecond accuracy of Internet time transfer is sufficient for many precise scientific applications. There may also be more scientific instruments in 2030 that will require a very accurate time and/or frequency signals to operate correctly. In high-end timing laboratories with high-end equipment, this is already the case. However, with the likely advent of precise time and frequency delivery over the Internet to a much wider population, it will be easy and inexpensive for manufacturers to design products that require precise time and/or frequency from an external source such as the Internet.

Hindrances, especially to the Internet 1-nanosecond prediction, are immense. It would likely be the combination of fiber-based networks, GPS III, and perhaps something such as PTP which would be necessary to establish 1-nanosecond time transfer through the Internet. Even then, it would take some coordination among all levels of Internet providers, from the maintainers of the backbone and the companies providing end users Internet access. Establishing justification for the organizations to coordinate will be paramount. It will be necessary to involve members of the associated sectors of industry with the PTTI field. The telecommunications and automotive industries, for example, have not really been a part of the PTTI Meetings held in the past. But, as PTTI applications extend the current PTTI community, the definition of the PTTI community will expand along with the attendance.

PROGRESS ON WIRELESS IEEE-1588

While wired IEEE-1588, known also as PTP, is predicted to be in widespread use by 2030, wireless support for IEEE-1588 will likely be infantile. In particular, wireless IEEE-1588 among networked devices that are all in motion and not moving exactly the same relative to each other will be important. Having a quality method of time transfer among close proximity wireless devices, all of which are in motion, will be very useful for automated vehicular travel. Current and future velocity information is then meaningfully transferrable from one vehicle to another. Distance can be determined from a PTP request. Relative velocity can be determined from successive wireless PTP requests.

Wireless IEEE-1588 will have numerous other applications as well. Use of wireless IEEE-1588 among mobile devices such as smart phones – maybe they will just be called phones by 2030 – will enable accurate timestamping. The technology could also be used in military applications as an inexpensive way to disseminate GPS-acquired time and frequency among groups, or as a backup method of time synchronization in the presence of jamming or when there is otherwise an inability to receive the GPS signals (e.g., when inside a building).

Acceptance could be an issue. A single, robust, unifying standard of time transfer applicable to wired and wireless network applications is preferable. There is, however, no reason that each cell phone vendor or car company will not implement their own method of accurate time transfer when and should the need arise. If past history is any indication, unless there is some extreme need for solidarity – such as in the home video market – we will have many solutions as opposed to one.

HOW ALL-OPTICAL NETWORKS HAVE REVOLUTIONIZED TIME TRANSFER

By 2030, there will likely exist an all-optical backbone to the Internet, with an optical link available to nearly everyone, as costs for this infrastructure will become increasingly affordable. Point-to-point connections on this optical Internet will be consistent. If necessary, there will be specialized hardware to accommodate the handling of timing packets to ensure repeatability of time transfer. This will be revolutionary for a multitude of reasons, not the least of which is the enormous bandwidth gain from using optical links. This will enable the transfer of very high-rate timing information among the major timing laboratories, allowing faulty, out-of-specification clocks to be recognized and mitigated sooner. It also means that any laboratory can make an inexpensive clock perform at a much higher level. The possibility may even exist for an accurate reference clock signal to be completely synthesized from remote Internet signals.

As with anything involving the Internet, there are a number of issues. There is no indication that an all-optical network designed to transfer data will be able to transport time as well. While it would likely be better than NTP is now, attaining accuracies necessary to compare reference atomic standards would be much harder to establish. An all-optical network strictly for time transfer could be established; however, the cost of laying such a network on a continental or intercontinental scale that is designed strictly for timing use would be very expensive, perhaps prohibitive.

ADVANTAGES OF AN IEEE-1588-ENABLED POWER GRID

Time synchronization in a power grid is very important to efficient transfer of the 50/60Hz AC power signal. In fact, power grids now make widespread use of GPS receivers specifically for precise time applications. The future use of 1588 in support of GPS or to replace GPS will reduce the cost and simplify the implementation of precise time in such grids. By 2030, and maybe even so today, the accuracy and certainly the reliability of PTP will be sufficient for the needs of the power industry. This will reduce the cost of upgrading and expanding the aging power grid in the United States. A GPS-synchronized power grid that uses PTP to distribute the time will have increased fault detection, be inexpensive to maintain, and be more efficient at power transfer.

One of the foreseen problems with IEEE-1588 will be the price of IEEE-1588-compliant devices needed to disseminate PTP time. By 2030, it may be a toss-up between establishing an IEEE-1588-compliant network and simply employing inexpensive GPS III receivers. It may be more cost-effective in 2030 to simply put a GPS III antenna/receiver combination at every node which requires a precise timing signal. However, a PTP setup with a good quality atomic standard synchronized to GPS and disseminated through PTP provides redundancy in case the GPS signal is jammed or otherwise disabled.

RESULTS FROM REAL-TIME DISTRIBUTION OF UTC (BIPM)

Real-time distribution of UTC (BIPM) will be a very important milestone. It should be noted that there will always be a slight delivery delay after the measurements are received from the laboratories to when the results are delivered, since the measurements need to be processed first. However, with a near-real-time stream of UTC (BIPM) data, the timing laboratories will be able to steer their timescales much more frequently to be coincident with UTC. Currently, UTC (BIPM) is a paper timescale that is updated once a month. A near-real-time distribution is still technically a paper scale, but can be realized much more closely by the laboratories around the world. Once realized, it will help bring all of the timescales of the world much, much closer together in time synchronization and syntonization.

By 2030, real-time UTC (BIPM) is predicted to have been available to PTTI users for some time. Most major laboratory timescales, for example UTC (USNO), will be able to make frequent and very small steering adjustments to be able to maintain time in near coincidence to UTC (BIPM). Only very precise applications will need to be converted from one timescale to another, much as is the case with terrestrial reference frames in 2010.

A couple of concerns with the emergence of a real-time UTC (BIPM) product were mentioned earlier in the paper. Another potential concern is manpower. Much work will be necessary to develop the algorithms necessary to handle the real-time data stream from many clocks. Also, there may be significant work required to assemble the programs and servers necessary to handle the many streams.

CONCLUSIONS

The core predictions that approximately eight individuals **[1]** made for 2030 are as follows: nanosecond-level time transfer through the Internet/GPS III, development of wireless devices compatible with the latest IEEE-1588 standard, widespread optical networks capable of precise time transfer, widespread power grid utilization of IEEE-1588 and GPS, and a real-time realization of UTC (BIPM). The papers predicted to be presented at the 62nd Annual PTTI meeting will likely introduce or report results of the technologies explored in this paper. Seeing the torrent of applications and advances that come from these core improvements will be breathtaking.

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